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Operations of the LEDA Resonantly-Coupled RFQ*

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The LEDA RFQ is a 350-MHz continuous-wave (CW) radio-frequency quadrupole linac. This machine has accelerated a 100-mA CW proton beam from 75 keV to 6.7 MeV. The 8-m-long RFQ accepts a dc, 75–keV, ~110-mA H^+ beam from the LEDA injector, bunches the beam, and accelerates it to full energy with ~94% transmission. Output beam power is 670 kW. The innovations that make this RFQ performance possible will be discussed. This RFQ consists of four 2-meter-long RFQs joined with resonant coupling to form an 8-meter-long RFQ. The resonant coupling improves the stability of both the longitudinal and transverse RF-field distribution in this long RFQ. Temporary adjustable slug tuners distributed along the outer walls were used to tune the RFQ. The program RFQTUNE was used to determine the length of these tuners. This program uses the measured field distribution to calculate a set of new tuner penetrations. The new set of tuner penetrations should change the field distribution to match the desired field distribution. After several iterations the field distribution closely matches the desired distribution and the permanent tuners are machined to length when the final tuning is complete. Further information is available [L. Young, "Tuning and Stabilization of RFQ's" *Proceedings of the 1990 Linear Accelerator Conference,* September 10-14,1990 Albuquerque, NM].

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Introduction

- The LEDA RFQ is the highest-energy RFQ in the world with a output proton beam energy of 6.7 MeV.
- The beam power when operated CW with 100 mA is 670 kWatts.
- We have operated LEDA for 111 hr of CW beam with > 90 mA.

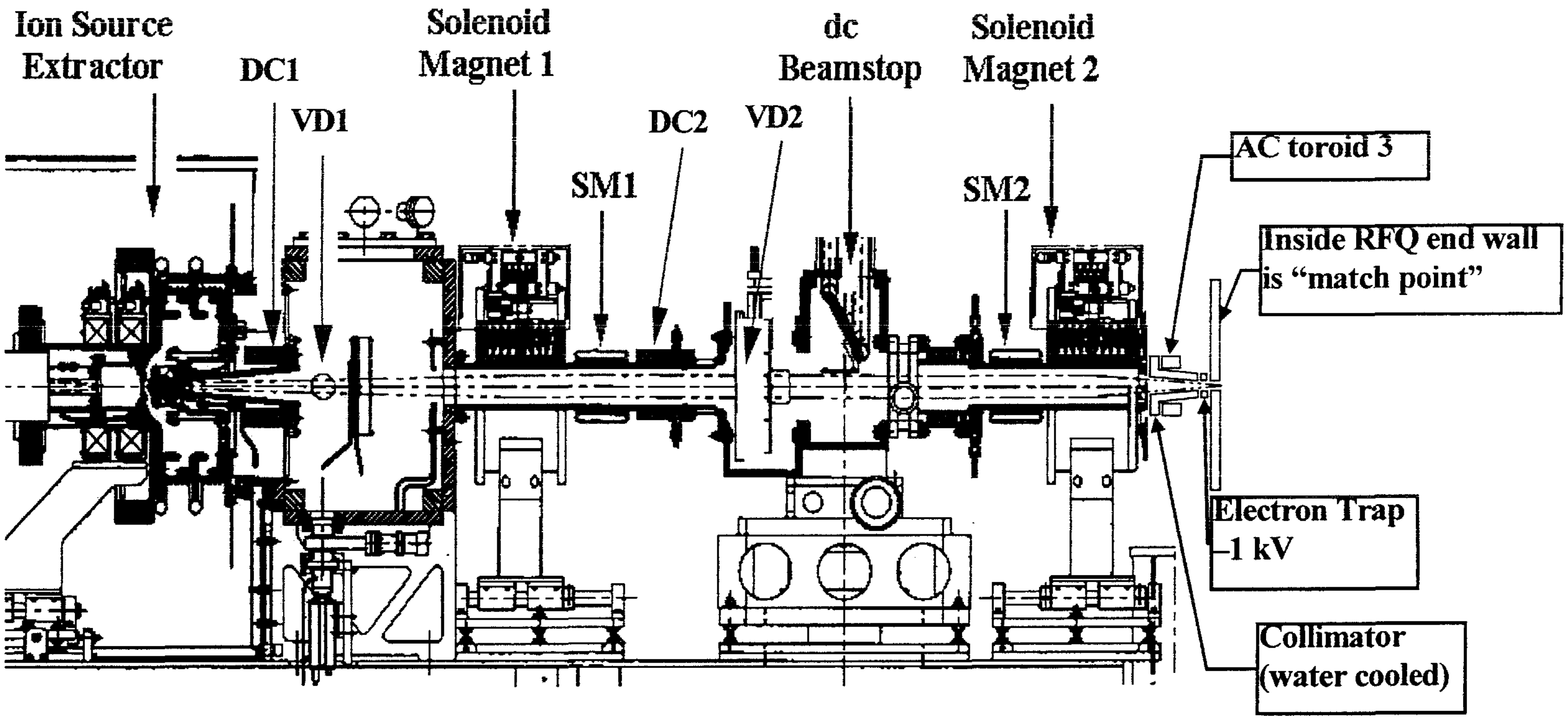
Unique Features of this RFQ are:

- Longest 4-vane RFQ in the world. (9 wavelengths long)
- Reduced transverse focusing at entrance for easier injection of beam.
- Increased aperture and gap voltage in the acceleration section of the RFQ.
- Reduced transverse focusing at exit of RFQ to match transverse focusing strength in the coupled-cavity drift-tube-linac (CCDTL) at 100 mA. (Current plans are to use a superconducting linac to accelerate beam currents ~10 mA.)

Resonant Coupling

- 8-m long RFQ is composed of four 2-m-long RFQs resonantly coupled together.
- First resonantly coupled RFQ.
- This resonantly coupled RFQ has field stability comparable to a 2-m-long RFQ.
- RF power from 3 klystrons coupled to RFQ through 6 waveguide irises.

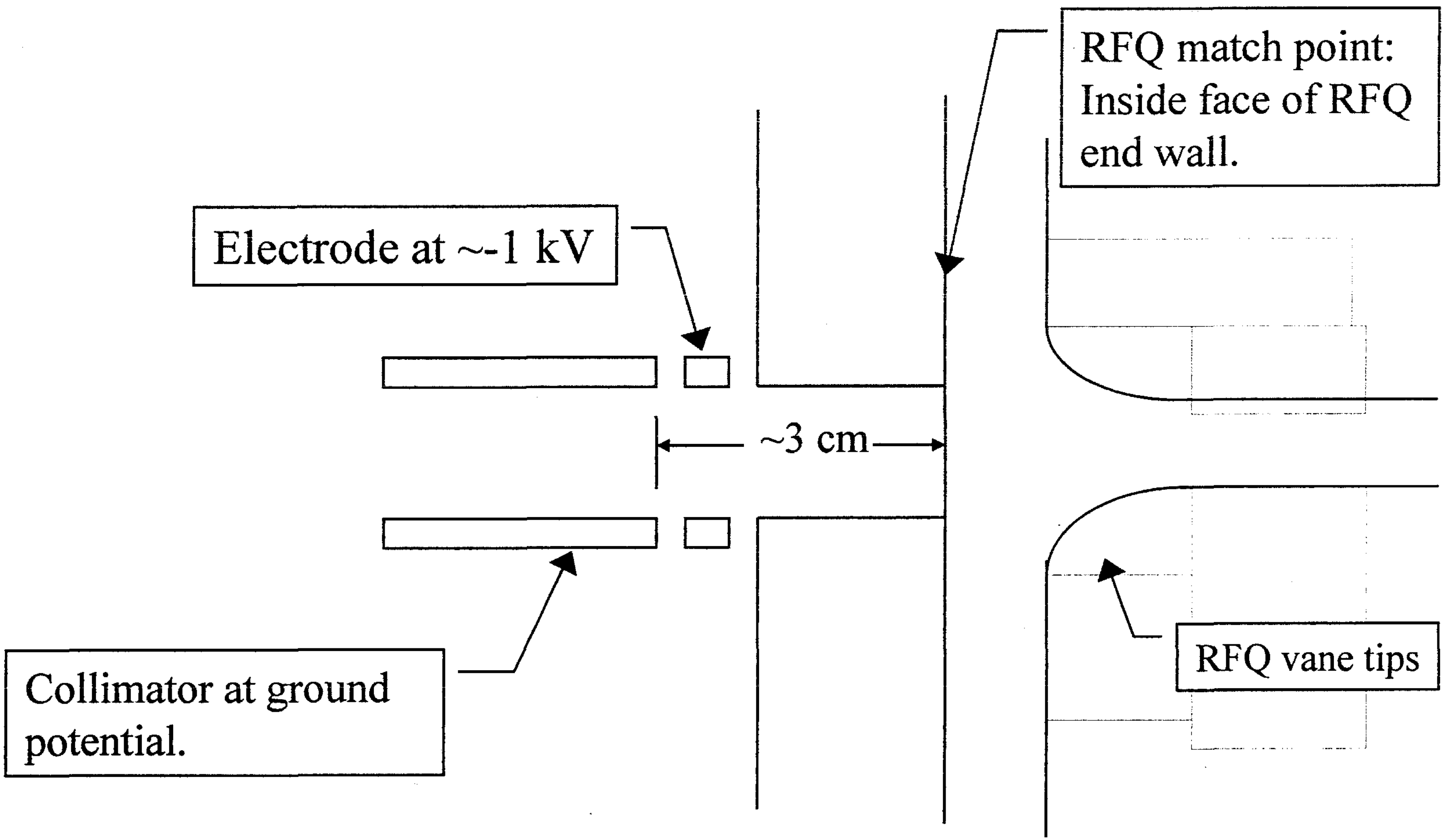
Low Energy Beam Transport (LEBT)



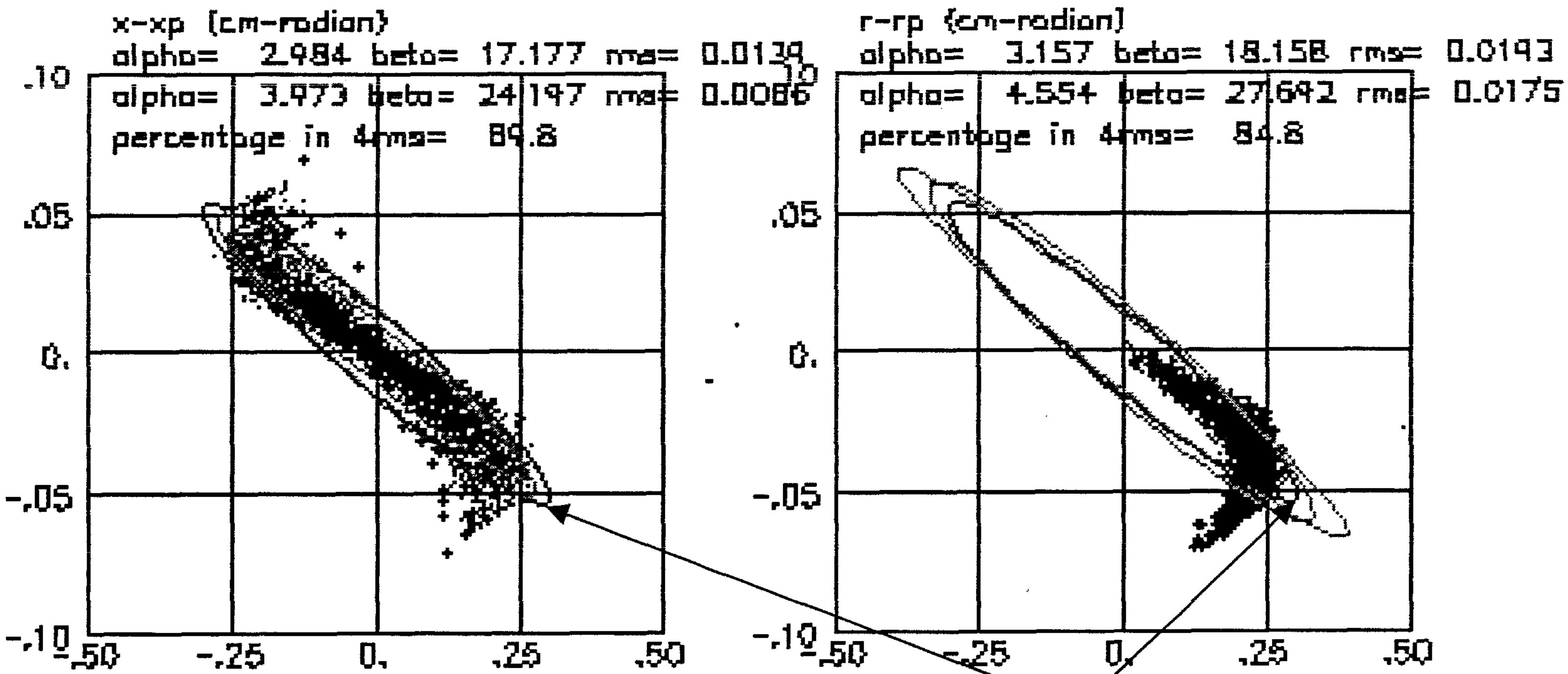
LEBT beam line with electron trap.

“E-trap” added to LEBT at entrance of RFQ.

Beam un-neutralized in last 3 cm drift to RFQ match point



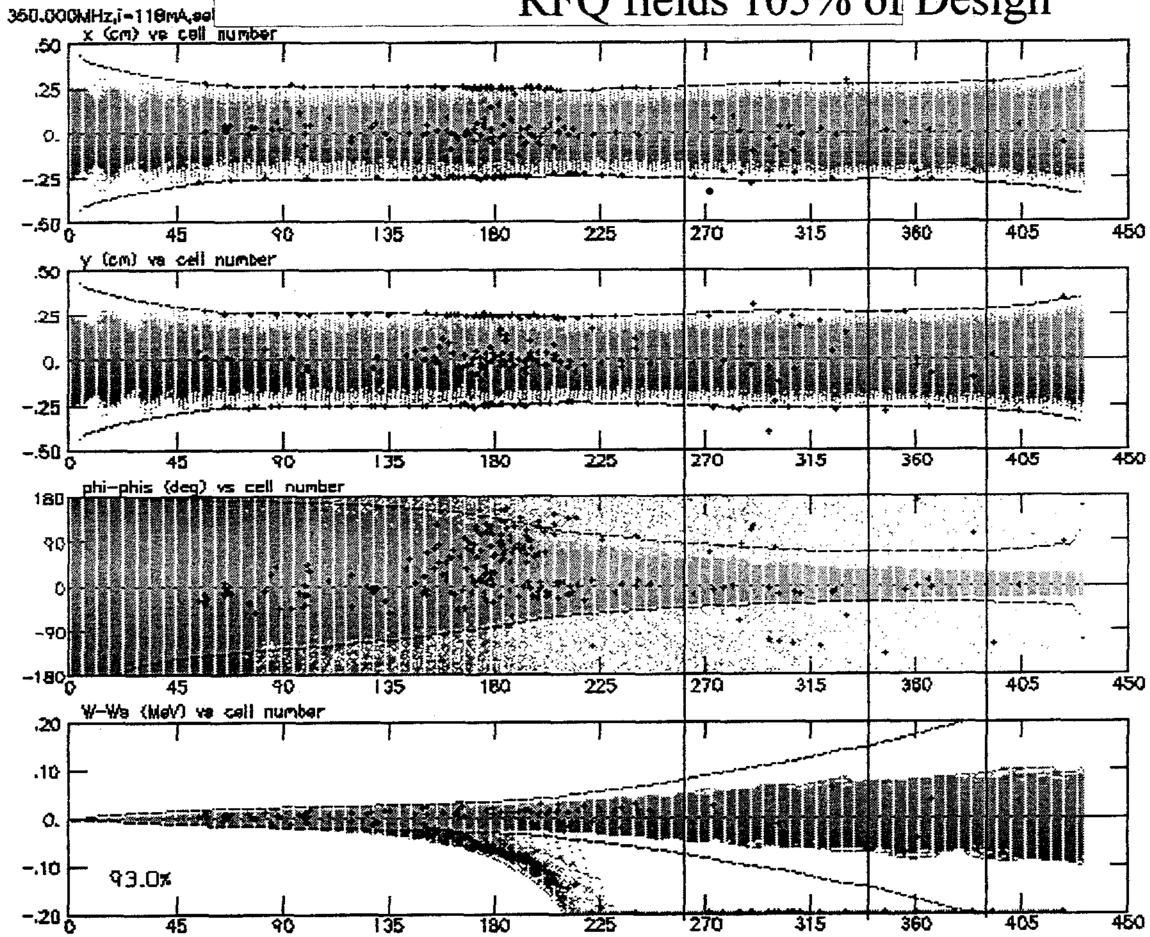
Phase-space at input to RFQ with solenoid 15 cm spacing and "e-trap"



Ideal shape of phase space ellipse to match beam into RFQ (.01 π mm-mrad.)

RFQ simulations show 93% transmission through RFQ using input distribution from PARMELA simulation of LEBT (15 cm solenoid spacing and "e-trap".)(108.5 mA in; 101mA out.)

RFQ fields 105% of Design

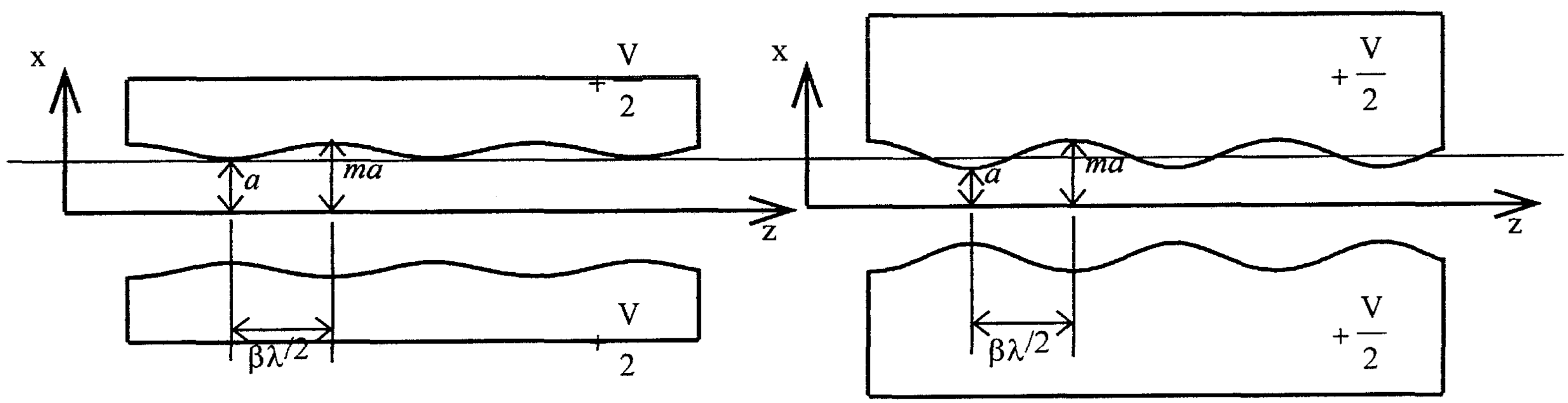


PARMTEQM simulation includes the effect of multipoles. The RFQ design has a radial matching section, a shaper section, a gentle buncher, an acceleration section, the "Crandall cell", and finally the fringe field exit region.

The RFQ code TOUTATIS gives similar results.

Acceleration Section

- Typically, as vane modulation increases to accelerate the beam, the aperture shrinks and beam can be lost on the vane tips.



Larger aperture and increased gap voltage shortens the RFQ.

- To reduce beam loss in this RFQ, we maintain a large aperture, but increase the vane voltage to keep the transverse focusing from decreasing too much as the vane modulation increases.
- The increased gap voltage increases the accelerating field substantially, which helps to shorten the RFQ.

Resonant Coupling

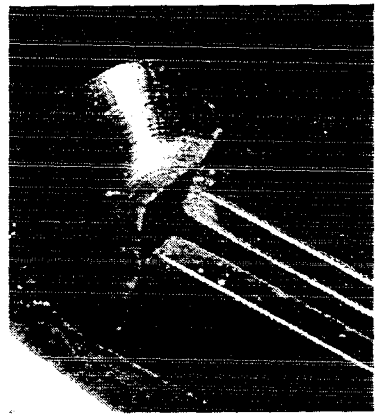
- The four 2-m RFQs are separated by coupling plates. An axial hole in the coupling plate allows the vane tips to nearly touch. There is 0.32 cm between the tips.
- This gap is placed so that as the bunch passes this gap the RF electric fields are crossing zero.
- The RF coupling between the RFQ sections is dominated by the electric field

Coupling Mode

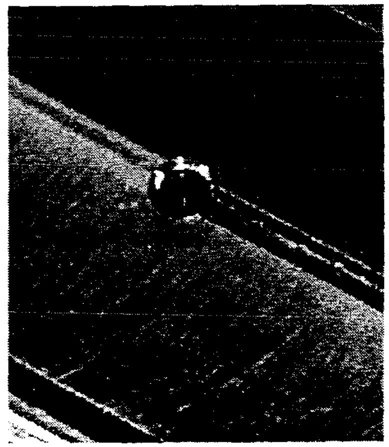
- Because the RFQ operates in "zero mode" the fields in all four sections are in phase.
- The "coupling mode" has strong electric field across the 3.2-mm gap between sections and has one longitudinal node in each 2-m RFQ section.
- The coupling mode's longitudinal component of the electric field transmits RF power, producing stability.

Some old problems we have solved

- The original wave guide irises melted with high average power (~ 1 MW) dissipated in the RFQ
- Multipacting in the tapered wave guide sections.
  - Reduced the number of waveguide feeds from 12 to 6. Now RF power is well above multipacting level.

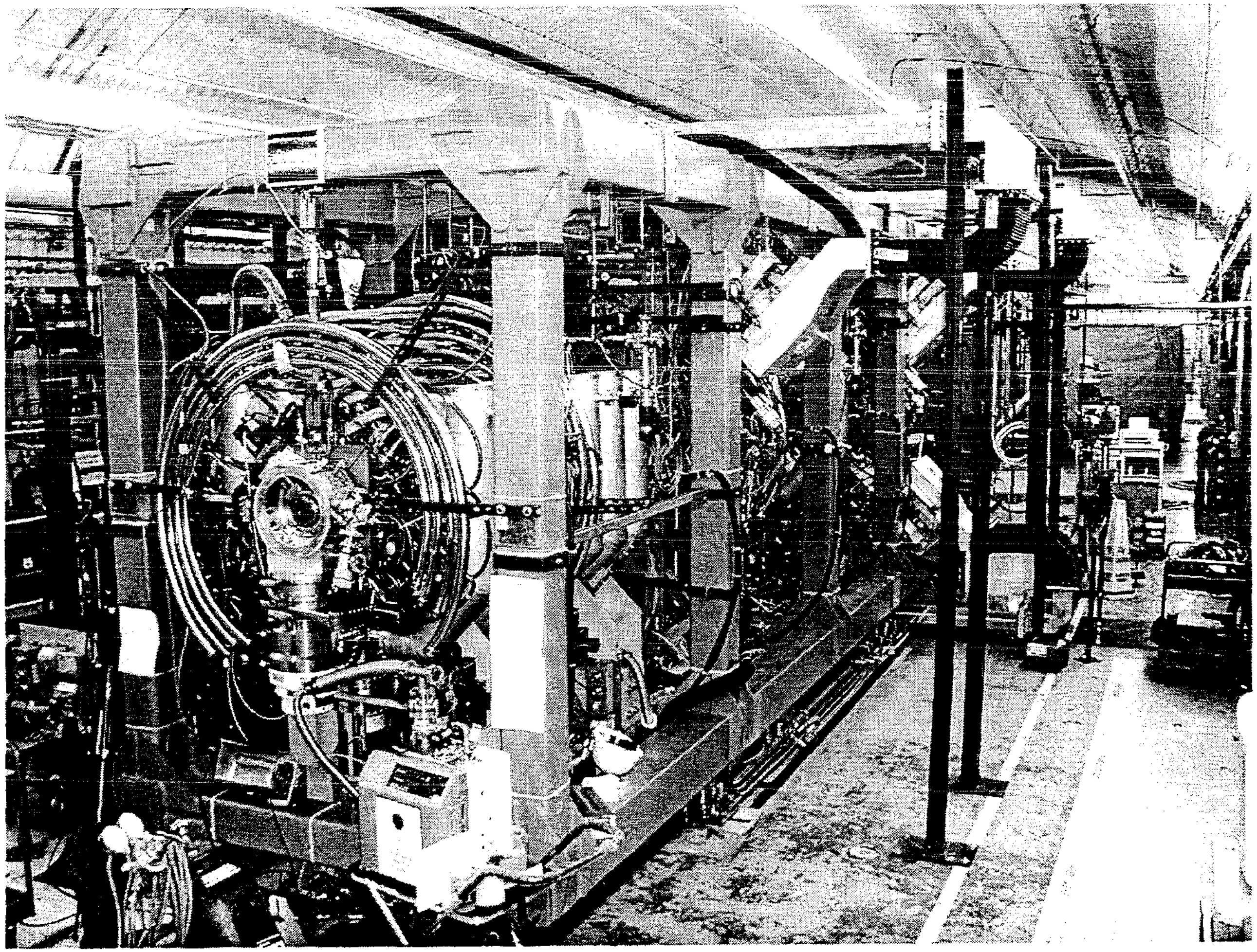


Melted iris.

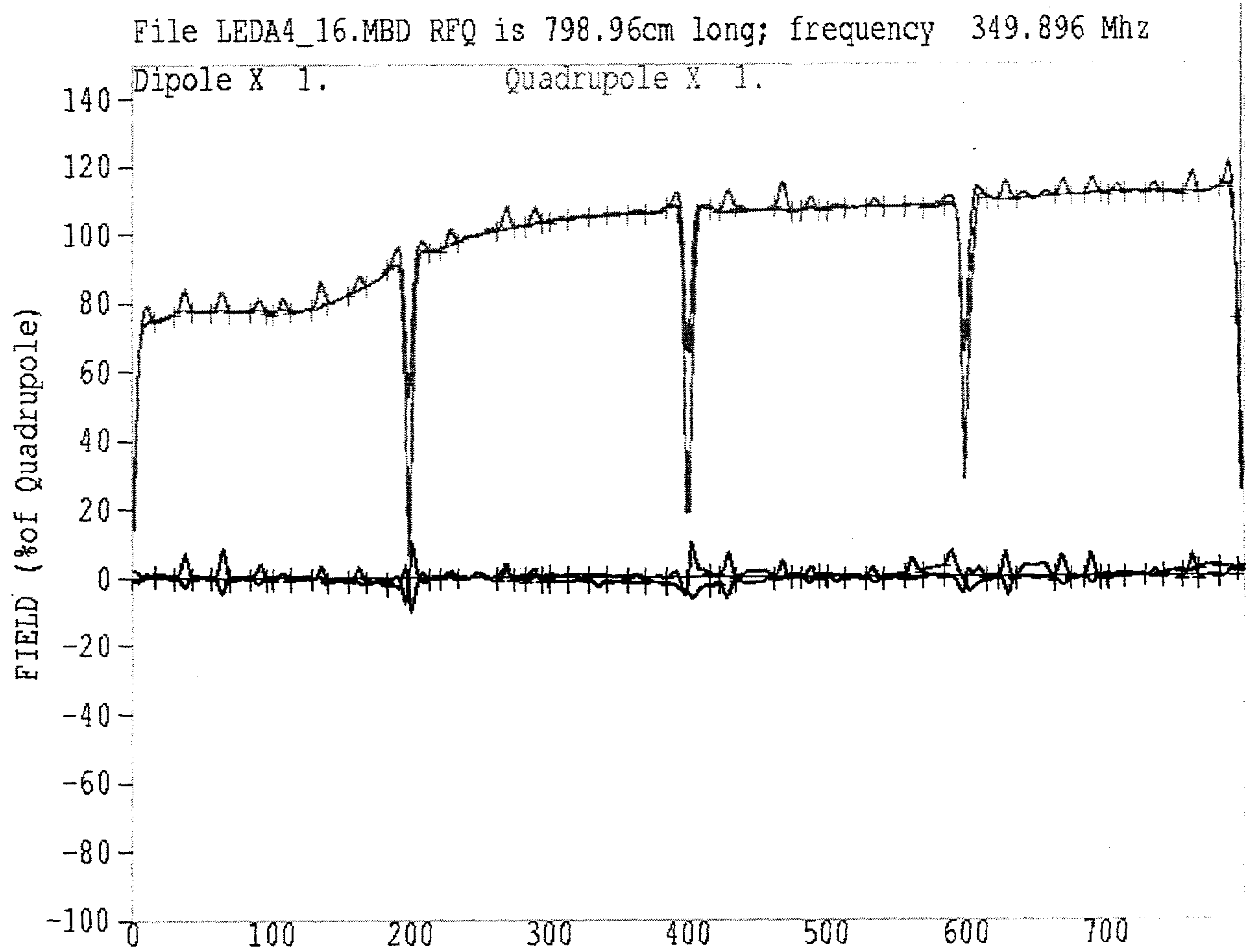


New thick walled iris

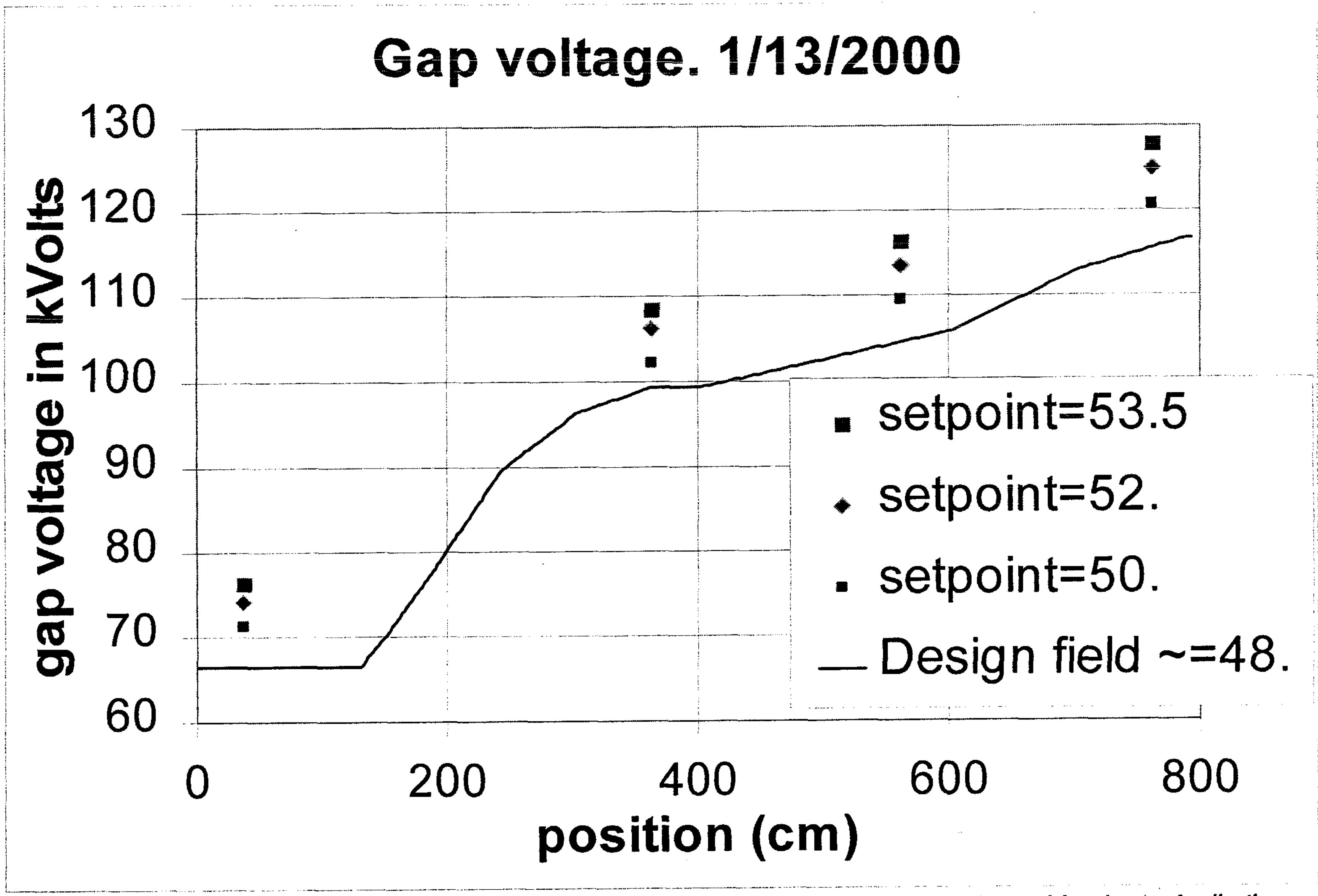
RFQ with 6 waveguide RF feeds.



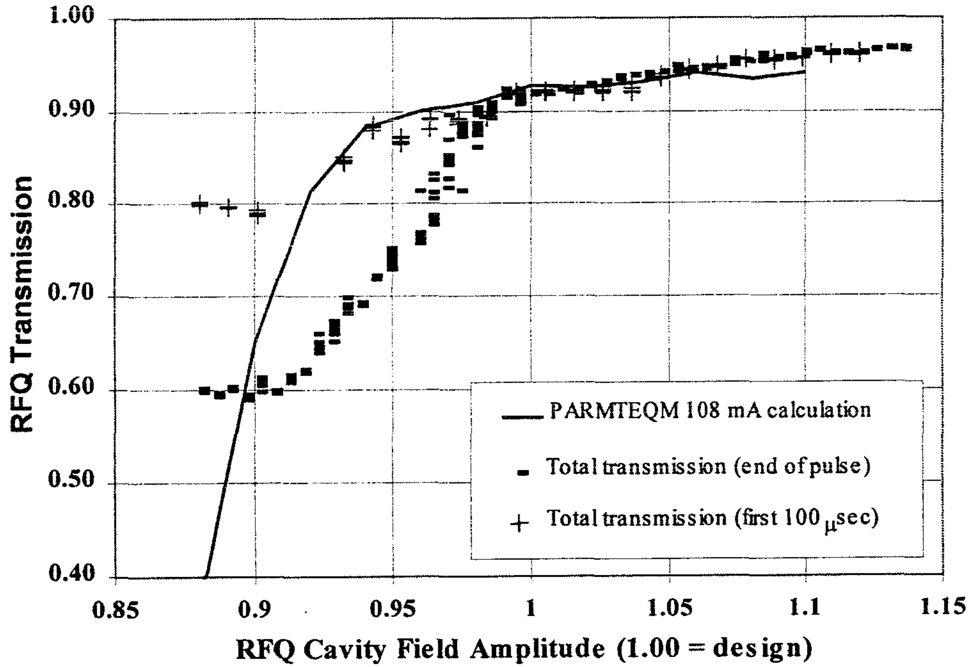
Final field measurement

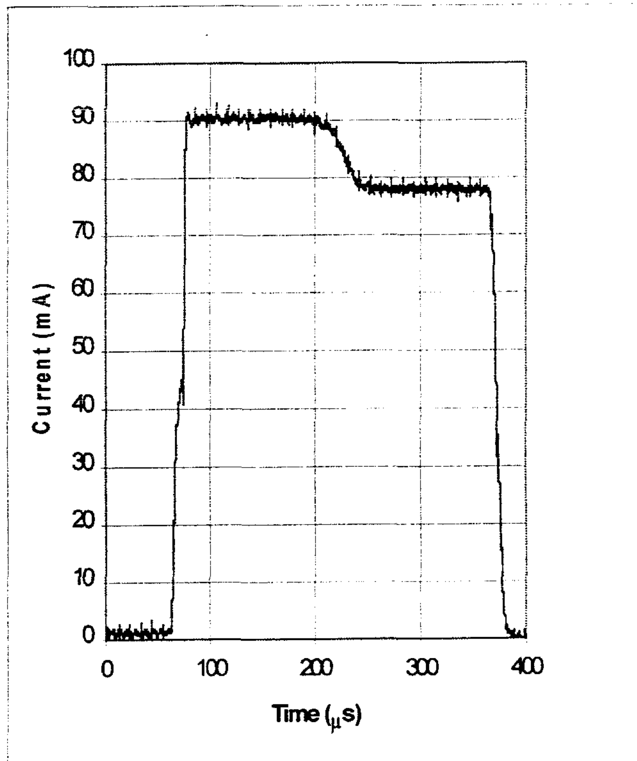


X-ray end point measurements at 4 locations in RFQ.



Transmission versus Set Point

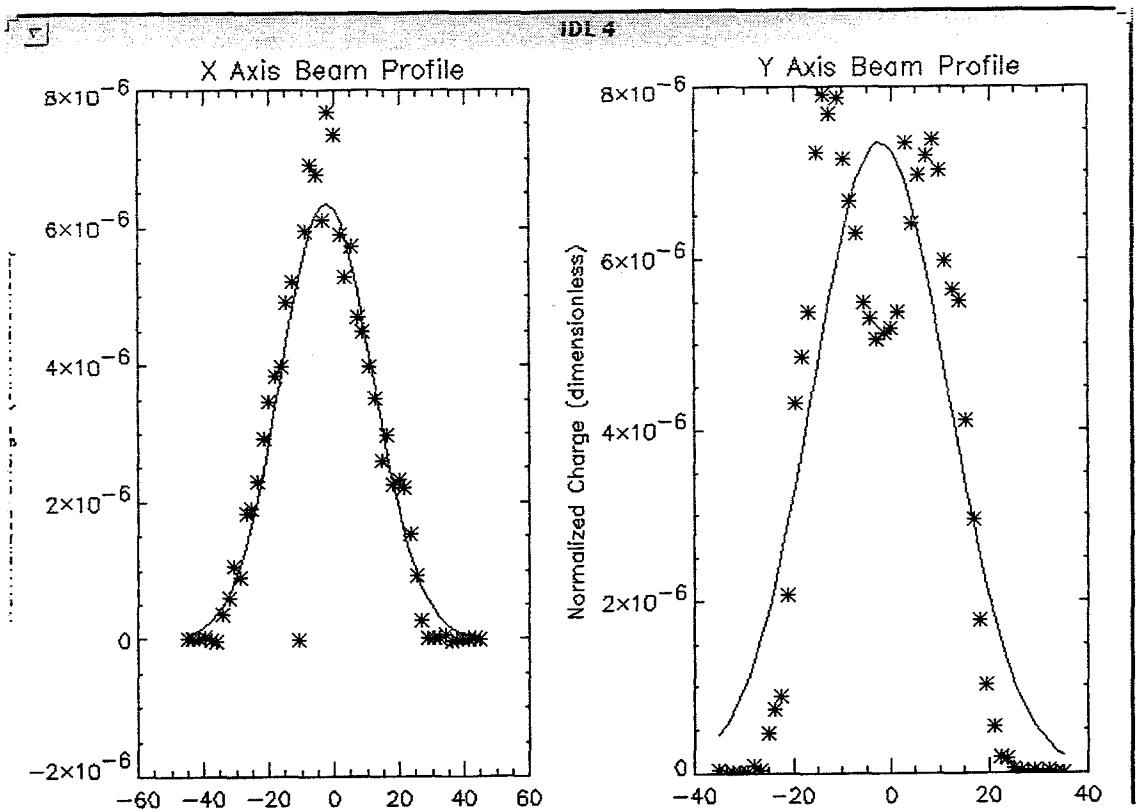




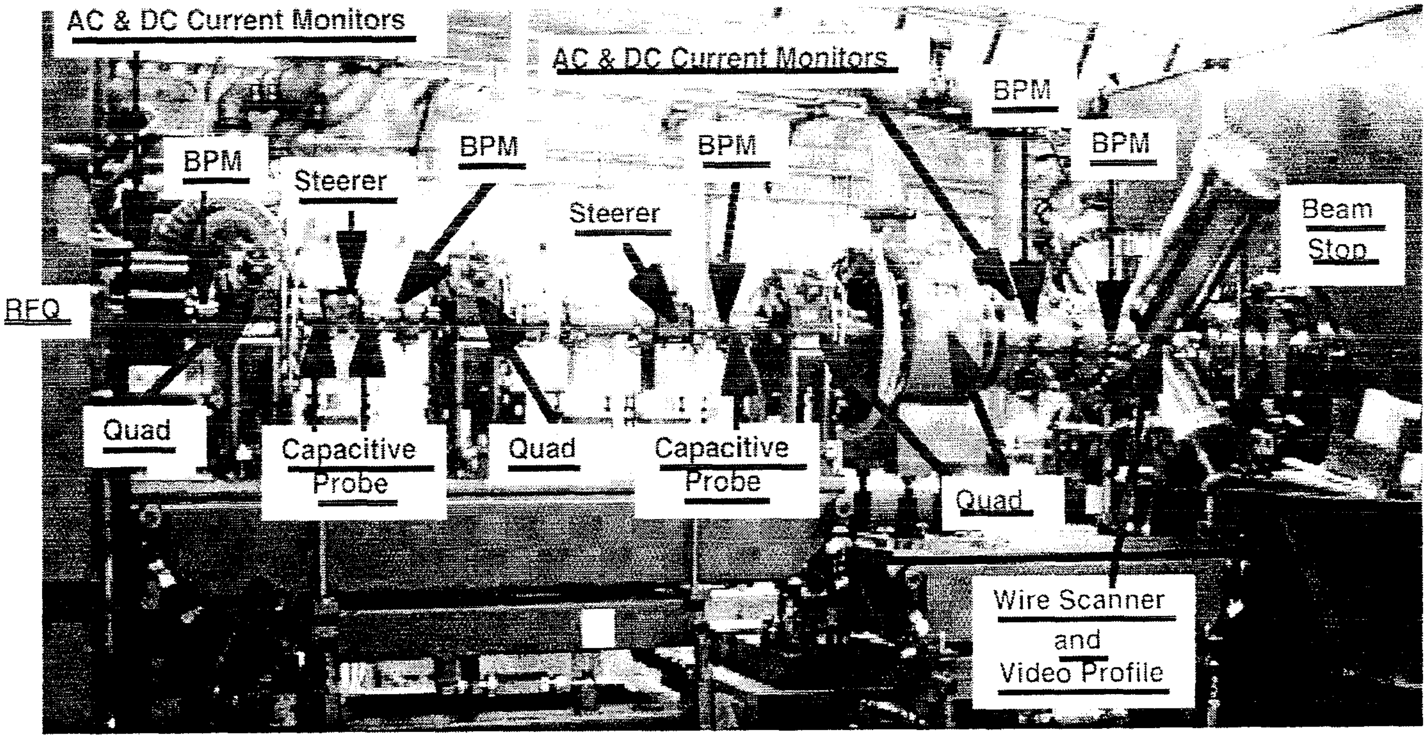
Loss of transmission may be caused by low-energy H^+ ions trapped near the axis by the RFQ fields

300 μs pulse with RFQ fields at 97%

Beam profile measured with wire scanner on low transmission part of beam pulse shown on previous slide.



HEBT



The High Energy Beam Transport line (HEBT). Beam tube radius only 5 times rms beam size.

HEBT beam profile matched to beam stop

Emittance

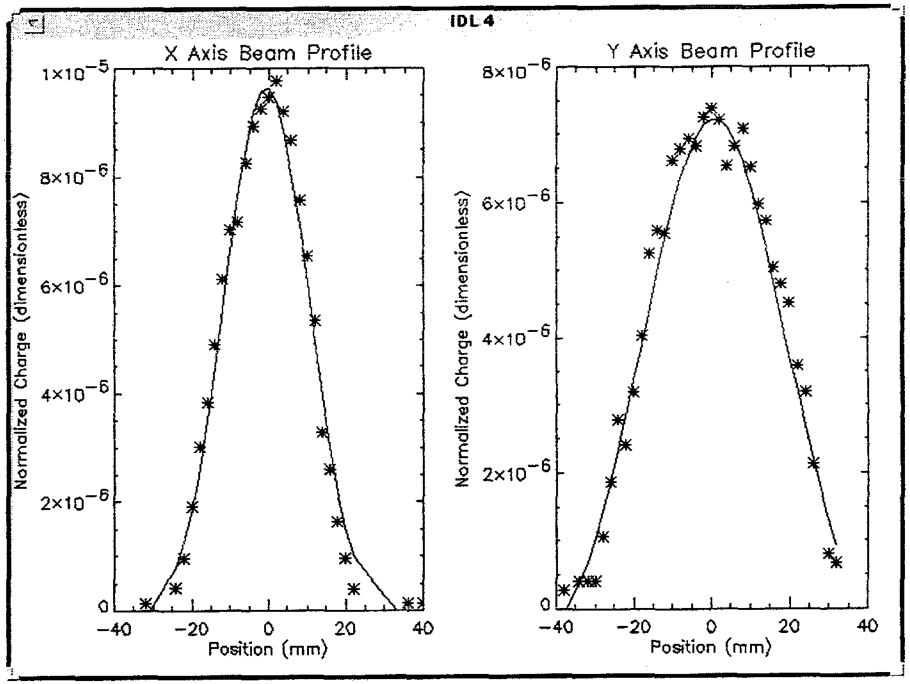
$\varepsilon \cong$ 1.8 mm mrad or less.

Normalize Emittance

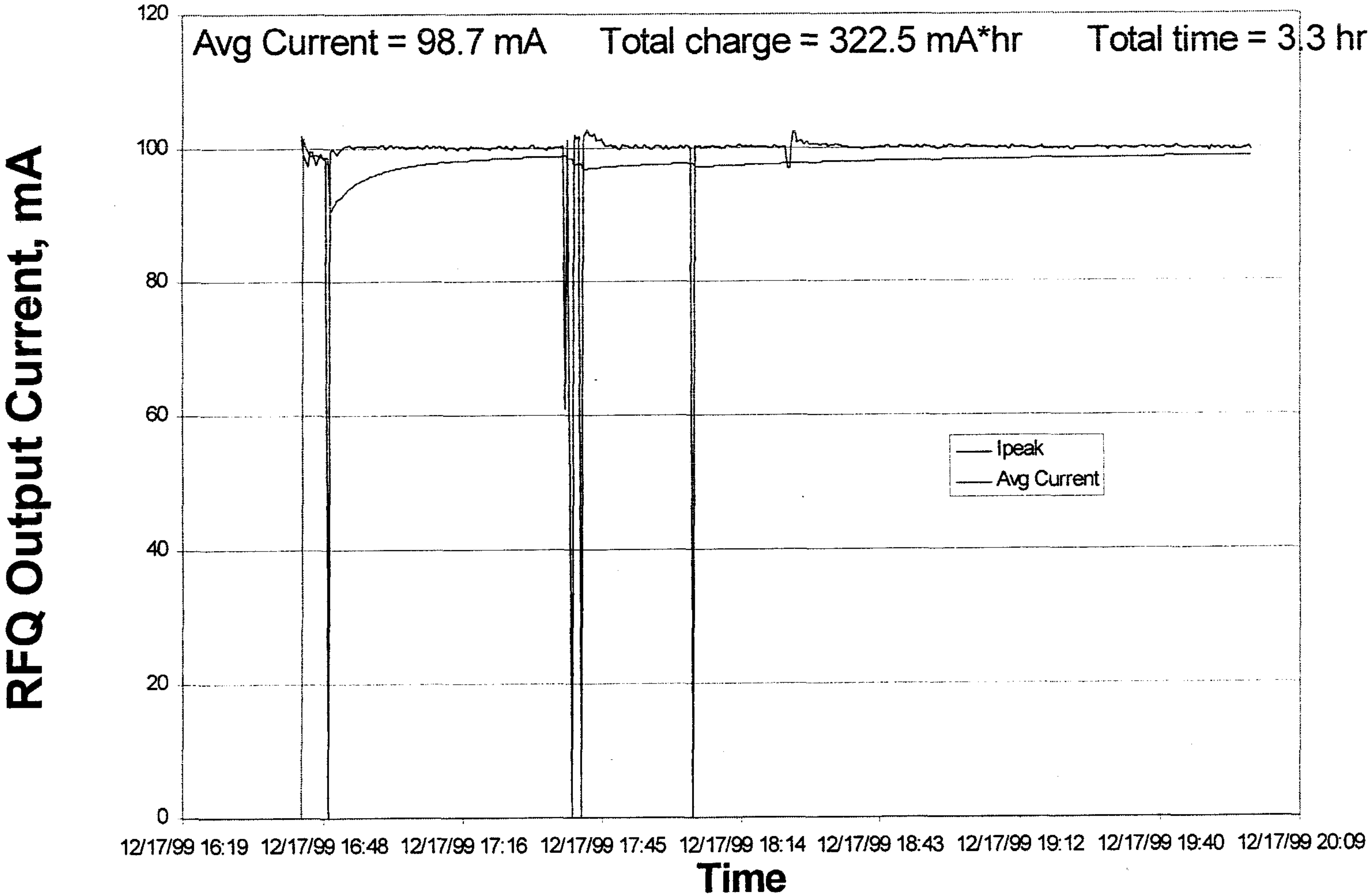
$\varepsilon \cong$ 0.215 mm mrad.

from 3D fit in paper RPAH089.

For more information see paper ROPA011.



A CW beam ~100 mA for 3.3 hr.



Summary

- LEDA RFQ has operated with $\geq$ 99 mA CW for 21 hr cumulative. (111 hr with $\geq$ 90 mA)
- The 8-m-long RFQ accelerates a dc 75-keV, 106-mA H^+ input beam to 6.7 MeV with ~94% transmission.
- RFQ operates best at field levels ~10% above design field levels.
- 670 kW output beam power.

Related Papers at PAC2001

- TOAA011 - "Measurement of Halos Generation for a Proton Beam in a FODO Channel," P. L. Colestock *et al*.
- RPAH089 - "Characterizing Proton Beam of 6.7 MeV LEDA RFQ by Wire-Scanner profiles to 3-D Nonlinear Simulations. W. P. Lysenko *et al.*
- ROPA011 - "Characterization of the Proton Beam from the 6.7-MeV LEDA RFQ," M.E. Schulze *et al.*
- RPAH032 - "Experimental Study of Proton-Beam Halo Induced by Beam Mismatch in LEDA," T. P. Wangler *et al.*
- ROAB004 - "Beam-Profile Instrumentation for Beam-Halo Measurement: Over all Discription and Operation," J. D. Gilpatrick *et al.*